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Source: *The Energy Journal*, Vol. 29, No. 2 (2008), pp. 165-184
Published by: International Association for Energy Economics
Stable URL: http://www.jstor.org/stable/41323162
Accessed: 19/09/2014 13:08

The Competitive Effects of Ownership of Financial Transmission Rights in a Deregulated Electricity Industry

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In this paper, we investigate how generators' ownership of financial transmission rights (FTRs) may influence the effects of the transmission lines on competition. In order for concrete analysis, a simple symmetric market model is introduced and FTRs are modeled in two different forms: FTR options and FTR obligations. This paper shows that introducing FTRs in an appropriate manner may reduce the physical capacity needed for the full benefits of competition. Among the competitive effects of ownership of FTRs, we focus on the effects on two possible pure strategy equilibria: the unconstrained Cournot equilibrium and the passive/aggressive equilibrium. We also analyze an extension of the model: asymmetric markets. Finally, a numerical illustration of applying the analysis is presented.

1. INTRODUCTION

Recently, the electricity industry is being restructured around the world. As restructuring continues to deepen, economic agents in the industry are interested in the impact of the unique characteristics of electricity on competitive electricity markets. One of the most important elements in a deregulated electricity industry with respect to competition among the generators is electric transmission facilities.

Much research has focused on understanding the roles of transmission networks in a deregulated electricity industry. Borenstein et al. (2000) studied the competitive effects of a transmission line that connects two electricity markets. They showed that there may be no direct relationship between the competitive effect of a transmission line and the actual line flow on the line. Moreover, with a sufficiently large capacity line, the full benefits of competition can be achieved

The Energy Journal, Vol. 29, No. 2.

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even in cases where the equilibrium line flow is zero. For sufficiently large line capacity, the market outcome is equivalent to the case where the markets are merged; that is, where there is unlimited capacity between the markets. Their work also included an empirical analysis of the California electricity market modeled as a duopoly. Willems (2002) studied a very similar market model to that of Borenstein et al. and investigated the role of the network operator for promoting competition among the generators. Quick and Carey (2001) applied the "dominant firm price-leadership model" to assess market power in Colorado's electricity industry and showed that strategies exist to reduce market power. Leautier (2000) studied regulatory contracts for the operators of transmission networks and proposed a regulatory contract that induces network operators to "optimally" expand the grid.

Stoft (1999) investigated market power issues when the generators serve a demand with capacity constrained transmission lines. He considered the effect on market power of financial transmission rights (FTRs) and the resulting distribution of the congestion rent. Joskow and Tirole (2000) also analyzed the market power effect of the allocation of transmission line rights in a more general context. In their work, they also discussed possible regulatory mechanisms. Cho (2003) investigated the competitive equilibrium in electricity markets over a network with finite capacity. He suggested a tool to check whether an equilibrium is efficient. He also examined markets for firm transmission rights in a market with a specific structure. Most recently, Gilbert et al. (2004) studied the market power effects of the transmission rights. In their work, the analysis has been performed for a simple two-node network model as well as for meshed networks.

In many restructured electricity markets, FTRs are used to hedge volatility in locational marginal price differences. In this paper, we analyze the effects of ownership of FTRs on the strategic behavior of the electricity generators in a Cournot framework. Following Borenstein et al. (2000), we primarily consider two markets that are identical in every respect, but geographically distinct. These two markets are linked by a single transmission line. We assume that each market has an identical monopoly supplier whose costs are identical to each other. The framework is similar to that of Borenstein et al. (2000), but generalizes it by considering transmission rights. We provide unified results by considering various FTR models, analyzing the effect on competition of FTR ownership by generators.

Joskow and Tirole (2000) also studied FTRs using a two-market model. Pritchard and Philpott (2005) considered a very similar model. However, in their analysis, they assumed that only one market has a demand and the other has only suppliers. They considered several alternative market power configurations; however, these are limited to monopolistic and oligopolistic competition only in one market with the other market competitive. This does not model the competitive effects of transmission rights in the more typical case where generators in both markets are imperfectly competing.

Cho (2003) analyzed electricity markets for firm transmission rights by a simple two-stage market model. This model consists of the first stage transmission right market and the second stage energy market. In this model, Cho assumed that players behave strategically in the first stage, but that they are price takers in the second stage. By analyzing equilibria, he showed that inefficient equilibria may exist. However, the market structure in his model is different from that of most actual electricity markets and his results cannot be directly applied to realistic electricity markets.

Gilbert et al. (2004) proposed a three stage game model considering first transmission right allocation and then trading, and finally output determination in the energy market. The model is solved backward, starting with the energy market. However, their proposed market model, in particular, the two-node network model is limited in the following manner. The model considers competition among the generators located only in one market and assumes the other market is perfectly competitive. As in Joskow and Tirole's model (Joskow and Tirole, 2000), this does not model the competitive effects of transmission rights when generators in different markets are imperfectly competing. Moreover, the transmission link is assumed always to be used at full capacity. Since this limitation will affect the results of each stage of the game and, in particular, affect the analysis of the energy market, which is the basis of their backward analysis, the final results may also be limited.

Many game-theoretic studies focused on the competitive effects of FTRs have tried to address mixed strategy equilibria. Borenstein et al. (2000) discussed it based on a numerical method. Gilbert et al. (2004) presented analytic results for mixed strategy equilibria but, due to the limitation of the model, their study could not be applied to the analysis of the competitive effects of transmission rights when generators in different markets are imperfectly competing. To the best of the authors' knowledge, no study so far has been performed for mixed strategy equilibria explicitly when generators in different markets are imperfectly competing under the transmission capacity constraint.

In this paper, we examine interactions between two incompletely competitive markets. In order to analyze the interplay of firms, a game-theoretic model, specifically a Cournot competition model, is adopted. In this setup, by examining best response curves, the effects of ownership of FTRs on achieving the unconstrained Cournot equilibrium are investigated. We show that by endowing generating firms with FTRs in an appropriate manner, from the generator to another market, the amount of the connecting line capacity needed for the full benefits of competition can be less than suggested by Borenstein et al.'s work. This direction of FTR hedges exposure to prices in the generator's market, mitigating its market power. In contrast, if generating firms possess FTRs from another market to the generator then there is a negative effect on competition. The latter FTR increases exposure to prices in the generator's market, increasing its market power. We also extend the model to include analysis of asymmetric markets and where one of the markets is competitive.

In Section 2, we describe the market model with two identical markets and two identical firms. In Section 3, we introduce the reference model without FTRs and then, following Hogan (2002), two different models: the FTR option model and the FTR obligation model. We analyze the best responses and possible equilibria in each model. The effects of each FTR model on pure strategy equilibrium are also investigated and policy implications for FTR ownership rules discussed. In Section 4, we extend FTR models first by considering asymmetry of markets and second by assuming that one of the markets is perfectly competitive. Section 5 presents a numerical example, and, finally, section 6 summarizes our results.

2. MARKET MODEL

Following Borenstein et al. (2000), we consider a model of two identical markets. Demand in each market is assumed to be identical and to be characterized by the same inverse-demand function denoted by $P : \Re_+ ® \Re_+$. These two markets are linked by a single transmission line whose capacity is K. In each market there is a single generating firm. We also assume that both firms have an identical cost function $C : \Re_+ ® \Re_+$. The transmission line is operated by a third entity and the pricing follows the nodal pricing rules (Schweppe et al., 1988) . Both generating firms try to maximize their profits by employing quantity strategies (Cournot).

In order for the model to be more concrete, we make the following assumptions:

- The inverse demand $P(q)$ in each market is represented by an affine curve with a negative slope:

$$P(q) = -\alpha q + \beta, \text{ where } \alpha, \beta \in \Re_+, \tag{1}$$

- Generating firms' generating costs $C(q)$ are represented by a convex quadratic function:

$$C(q) = -a/2\, q^2 + bq + c, \text{ where } a, c \in \Re_+, \text{ and } b \in \Re. \tag{2}$$

3. COMPETITIVE EFFECTS OF FINANACIAL TRANSMISSION RIGHTS

In this section, we derive analytical expressions for the best response of each firm for a reference model without financial transmission rights (in section 3.1) and for two models of financial transmission rights (FTR) (Hogan, 2002): the FTR option model (in section 3.2.1) and the FTR obligation model (in section 3.2.2). We also analyze the competitive effects of the corresponding financial transmission rights for each model using best response analysis. However, for the brevity of the paper, we only present the detailed analysis for the reference model and the FTR option model. For the FTR obligation model, only the results are summarized.

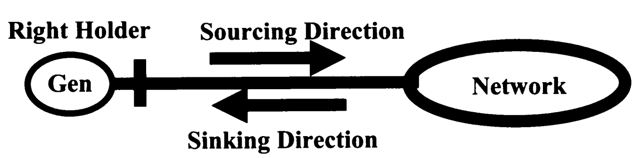
Following Borenstein et al. (2000), for the best response analysis, we define two categories of optimal responses: optimal aggressive output and optimal passive output. First, suppose that firm i is in the situation such that the opponent, firm j, is producing nothing (more generally, that firm j is producing so little energy that there is transmission congestion on the line in the direction from market i to market j). In this case, the best response of firm i is to produce its optimal quantity given that the line is congested from i to j. Under the nodal pricing scheme, this quantity will be the same as the monopoly output for firm i when the market is isolated but with the demand shifted to the right by K. We call this the optimal aggressive output for i and denote it with a superscript +.

Now, suppose that firm i is in the situation such that the opponent, firm j, is producing a great amount of electric power (more generally, firm j is producing enough energy to cause line congestion from market j to market i). In this case, the best response of firm i is to produce its optimal quantity given that the line is congested in the direction from market j to market i. Under the nodal pricing scheme, this quantity will be the monopoly output for firm i when the market is isolated with the demand shifted to the left by K. This monopoly quantity is called the optimal passive output for i and will be denoted with a superscript –.

Besides the optimal aggressive and passive outputs, one more category of best response behavior is needed to cover the uncongested case. Since the resulting quantity is equivalent to the unconstrained Cournot best response output for the merged markets, we call this output the Cournot best response output and denote it with a superscript C.

An FTR is a financial contract for collecting an amount of money determined by the difference between two nodal prices. We define the "direction" of FTRs from the point of view of the generating firm that holds the transmission rights. We say the "sourcing" direction for FTRs that are in the direction from the market where the right holding generating firm is located to the other market. That is, the payoff of sourcing FTRs is defined by the nodal price in the other market minus the nodal price at the generator. We call the opposite direction the "sinking" direction. That is, the payoff of sinking FTRs is defined by the nodal price at the generator minus price in the other market. These two directions are illustrated in Fig. 1.

Figure 1. FTR Directions



3.1 Reference Model

As a reference model, we consider the case such that neither firm has any rights on the transmission line. We will denote the reference case with a superscript r. In this case, the optimal aggressive and passive outputs, and the Cournot best response output, which are denoted by $q^{r+}(K)$, $q^{r-}(K)$, and $q_i^{rC}(q_j)$ respectively, are expressed by (3), (4) and (5).[1]

$$q^{r+}(K) = \frac{\beta + \alpha K - b}{2\alpha + a}, \tag{3}$$

$$q^{r-}(K) = \frac{\beta - \alpha K - b}{2\alpha + a}, \tag{4}$$

$$q_i^{rC}(q_j) = -\frac{\alpha}{2(\alpha + a)} + \frac{\beta - b}{\alpha + a}. \tag{5}$$

Here, we can observe that the function q^{r+} is increasing in its argument while the function q^{r-} and the function q_i^{rC} are both decreasing in their argument (Note that q^{r+} and q^{r-}. are functions of line capacity K, while q_i^{rC} is a function of production by the other firm, q_j.).

This reference model is equivalent to the symmetric two-firm model of Borenstein et al. (2000). This section serves to review their results. The line will be congested only when the difference between the outputs of two firms is greater than $2K$, since otherwise, by transferring a smaller amount of electricity than the line capacity K, the two markets' prices would be equalized.

Let us consider the best response of firm i with respect to the other firm j's strategy, q_j. When firm j is producing any amount up to $q^{r+}(K) - 2K$, firm i can maximize its profit by producing the fixed amount $q^{r+}(K) - 2K$. As firm j's output increases above $q^{r+}(K) - 2K$, however, firm i can maximize its profit and still export K by producing $2K$ more than firm j. That is, firm i maximizes its profit by producing $q_j + 2K$, accounting for the segment of slope 1 in the best responses shown in Fig. 2. Note that as q_j keeps increasing, firm i's resulting payoff from maintaining an aggressive response is decreasing. As firm j's output continues to increase, we can think of two situations.

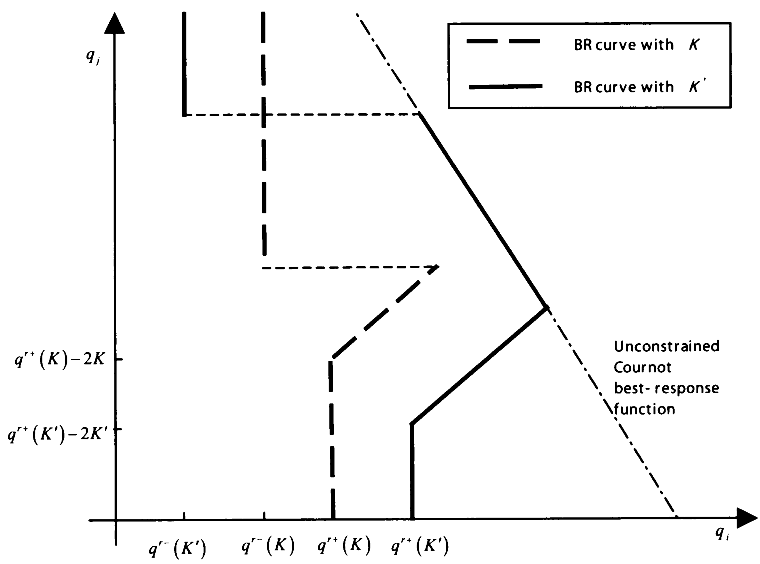
On the one hand, if K is small, then producing the optimal passive output $q^{r-}(K)$ becomes more profitable for firm i before the value of $q_i = q_j + 2K$ reaches the unconstrained Cournot best response $q_i^{rC}(q_j)$. This is shown by the dashed curve in Fig. 2.

On the other hand, if the line capacity is large enough, say, $K' > K$ as shown in Fig. 2 as the solid curve, then firm i's best response will change from $q_j + 2K$ to $q_i^{rC}(q_j)$. However, even in this situation, as q_j keeps increasing, producing $q^{r-}(K)$ will eventually be more profitable for firm i than producing $q_i^{rC}(q_j)$. This accounts for the transition in the best responses to $q^{r-}(K')$ and $q^{r-}(K)$, respectively, for high enough q_j.

1. There is no case where (3) and (4) are achieved in an equilibrium in a symmetric model; however, in an asymmetric model, passive/aggressive equilibria are possible, in which case a pair of (3) and (4) will be an equilibrium output pair.

To summarize, the situations for the two values of line capacity are illustrated in Fig. 2. The solid curve shows the case of relatively large capacity K' where firm i's optimal response includes some values equal to the Cournot unconstrained best response. The dashed curve shows the case of relatively small capacity K where the best response never includes values equal to the Cournot unconstrained best response.

Figure 2. Best Response Curves For Firm *i* ($K < K'$).



As shown in Fig. 2, the best responses of both firms will have different characteristics according to the transmission line capacity K. Specifically, increase of physical line capacity implies both increase of the optimal aggressive output $q^{r+}(K)$ and decrease of the optimal passive output $q^{r-}(K)$. Borenstein et al. (2000) shows that this, in turn, implies an increase in the competion-promoting effects of the transmission line:

- decrease in the equilibrium price of the mixed strategy equilibrium, and
- increase in the range of market demand conditions that result in the pure strategy Cournot equilibrium.

The results of Borenstein et al. (2000) also shows that if K is very small, then there is no pure strategy equilibrium, while if K is large enough, the Cournot duopoly equilibrium will be reached as the unique equilibrium. That is, the equilibrium is specified by (5), with zero flow along the line but with the line providing the full competitive benefits of merged markets.

3.2 FTR Option and Obligation Models

An FTR option is a financial contract for collecting the amount of money determined by the locational price difference and the share of the right. This option gives the owner the right to collect a portion of the congestion rents when the price difference is positive, but does not require payment when the price difference is negative.

An FTR option has a specified exercise direction and if the nodal price difference is positive in this direction, then the FTR provides a positive payoff. There is zero payoff for price differences in the other direction. This means that each firm i has two possible directions for his FTR option in this two market model; that is, a direction from market i to j (the sourcing direction) and one from j to i (the sinking direction). We analyze each directional FTR option separately. FTR options are implemented in the Electric Reliability Council of Texas (ERCOT) zonal balancing market as "flowgate" rights (ERCOT, 2005) and are being introduced in several other markets in the United States, including the ERCOT "nodal" market in 2009 (ERCOT, 2006).

An FTR obligation is a similar financial contract to an FTR option, but it has negative payoff if the nodal prices reverse. That is, if the price difference is positive, a holder collects the congestion rents of the transmission line, while for the negative price difference, the holder makes a payment. Obligation-type rights also have two possible directions. FTR obligations are implemented in several markets in the Eastern US, including PJM (PJM, 2005), and will also be available in the ERCOT nodal market (ERCOT, 2006).

For the brevity of the paper, the detailed analysis is presented only for the FTR option model. For the FTR obligation model, only a summary of the results of the analysis is provided while the detailed analysis is presented in Joung's dissertation (Joung, 2008).

3.2.1 FTR Option Model

Let η_i^{ij} and η_i^{ji} denote generating firm i's FTR option share from market i to j and from market j to i, respectively, such that $\eta_i^{ij}, \eta_i^{ij} \in [0,1]$. That is, η_i^{ij} describes the share of sourcing FTR, while η_i^{ji} describes the share of sinking FTRs. We use superscript *uo* to denote options.

We have:

Lemma 1. Let q_i^{uoij+}, q_i^{uoij-}, and q_i^{uoijC} be the optimal aggressive, passive, and Cournot responses for firm i holding share η_i^{ij}. Let q_i^{uoij+}, q_i^{uoij-}, and q_i^{uoijC} be the optimal aggressive, passive, and Cournot responses for firm i holding share η_i^{ji}. Then:

$$q_i^{uoij+}(K, \eta_i^{ij}) = q^{r+}((1 + \eta_i^{ij})K), \tag{6}$$

$$q_i^{uoij-}(K) = q^{r-}(K), \tag{7}$$

$$q_i^{uoijC}(q_j) = q_i^{rC}(q_j), \tag{8}$$

$$q_i^{uoji+}(K) = q^{r+}(K), \tag{9}$$

$$q_i^{uoji-}(K, \eta_i^{ji}) = q^{r-}((1 + \eta_i^{ji})K), \tag{10}$$

$$q_i^{uojiC}(q_j) = q_i^{rC}(q_j), \tag{11}$$

Proof: See Joung's dissertation (Joung, 2008)

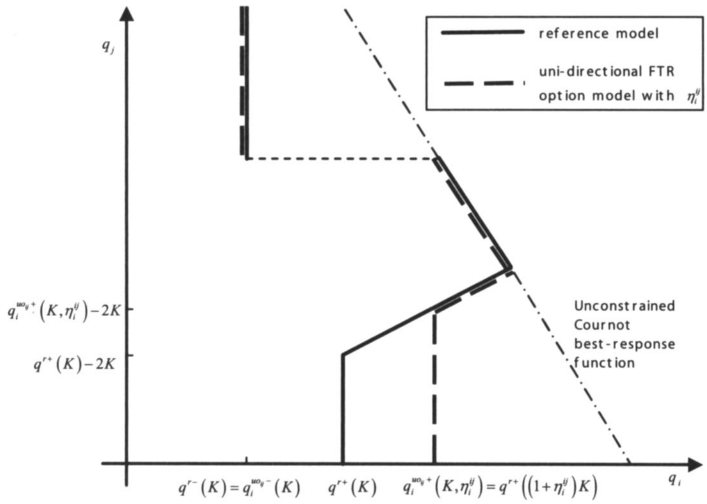
Lemma 1 suggests that the ownership of an FTR option is equivalent to expanding the capacity of the line in one direction. This specific relationship is mainly from the linearity of demand. When we relax the demand linearity, this relationship would change, but we would expect a similar qualitative effect.

To summarize, an FTR option results in the change of either the optimal aggressive output (see (6)) or optimal passive output (see (10)) compared to the reference model. By possessing an η_i^{ij} FTR option, firm *i*'s optimal aggressive output increases as indicated by (6), observing that by (3), q^{r+} is increasing in its argument. By possessing an η_i^{ji} FTR option, firm *i*'s optimal passive output decreases as indicated by (10), observing that by (4), q^{r-} is decreasing in its argument. The change of the best response due to an FTR option is illustrated in Fig. 3. Note that, in order to differentiate two different response curves in Fig. 3, there are some line segments that are illustrated as being close together although they are in fact coincident.

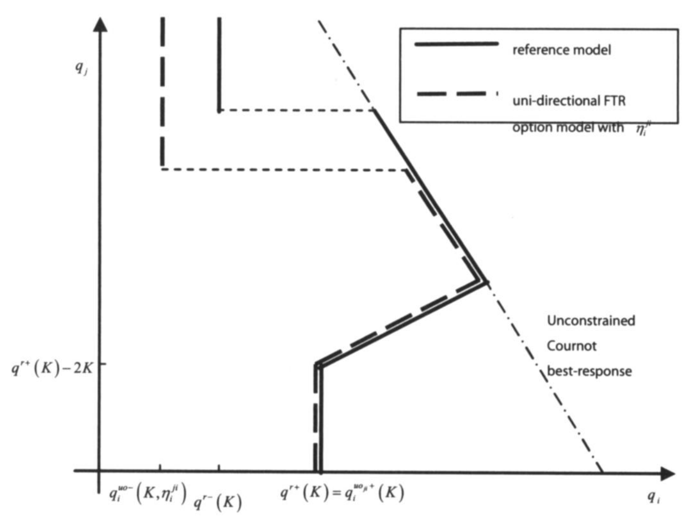
As shown in Fig. 3, according to its direction, each FTR option has one of two different effects: either increase of the optimal aggressive output as shown in Fig. 3(a) or decrease of the optimal passive output as shown in Fig. 3(b). This, in turn, affects the range of conditions for realization of the pure strategy equilibrium. Here, we focus on the effect on the occurrence of three forms of equilibrium: the unconstrained Cournot equilibrium, passive/aggressive equilibrium, and mixed strategy equilibrium (Borenstein et al., 2000). We do not consider overlapping equilibria as described in the work of Borenstein et al. (2000).

Increase of the optimal aggressive output has no effect on achieving the unconstrained Cournot equilibrium since the unconstrained Cournot best response region is the same as that in the reference case and the range of conditions for the unconstrained Cournot equilibrium will be also the same as shown in Fig. 3(a). On the other hand, decrease of the optimal passive output reduces the unconstrained Cournot best response region since the right holder becomes more inclined to the optimal passive output. That is, the transition of its best response from the unconstrained Cournot response to the optimal passive output occurs at a smaller value of the other firm's output as shown in Fig. 3(b).

Figure 3. Comparison of Best Response Curves



(a) Best Response Curves for firm *i* Without FTRs and With η_i^{ij}.



(b) Best Response Curves for firm *i* without FTRs and with η_i^{ji}.

Consider a case where, without FTRs, the capacity of the transmission line is enough to achieve the unconstrained Cournot equilibrium. Fig. 4(a) illustrates this case. From the previous argument, if firm i possesses an η_i^{ij} FTR option and/or firm j possesses an η_i^{ji} FTR option, then the resulting equilibrium will be the same as the unconstrained Cournot equilibrium in the reference case as shown in Fig. 4(b).

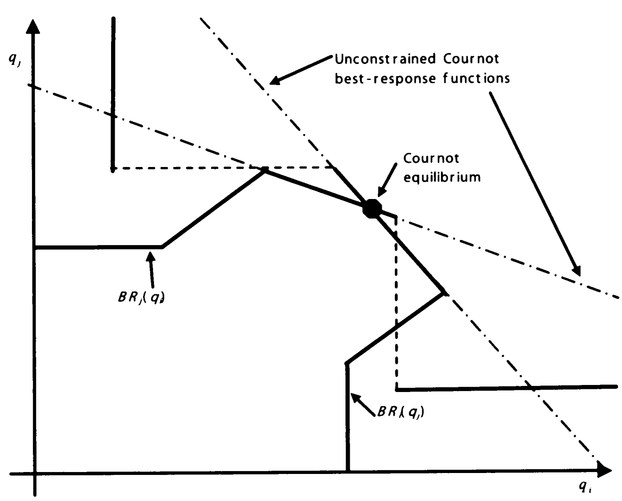
In contrast, suppose that firm i possesses an η_i^{ji} FTR option. In this case, the resulting equilibrium may change from the unconstrained Cournot equilibrium to a mixed strategy equilibrium. This is illustrated in Fig. 4(c). Fig. 4(c) shows that by i possessing an η_i^{ji} FTR option, the change of best response curve of firm i may result in a mixed strategy equilibrium instead of the unconstrained Cournot equilibrium that is achieved without FTRs (Fig. 4(a)). A similar effect can occur if firm j possesses an η_i^{ij} FTR option.

However, for the range of $\eta_i^{ij} \in [0,1]$, the introduction of FTR options cannot create enough asymmetry to yield a passive/aggressive equilibrium.

Lemma 2. Suppose that, without FTRs, the capacity of the transmission line is enough to achieve the unconstrained Cournot equilibrium. In this case, by firm i's possessing an η_i^{ji} FTR option, the resulting equilibrium cannot change to a passive/aggressive equilibrium.

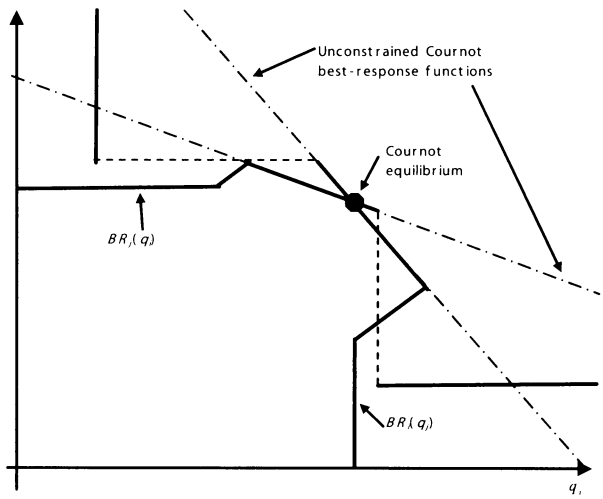
Proof: Suppose that, with firm i's possessing an η_i^{ji} FTR option, a passive/aggressive equilibrium is achieved. Then, the price difference $P_{ij}(q_i,q_j)$, between two markets is obtained as:

Figure 4. Illustration of the Effects of FTR Options on the Cournot Equilibrium

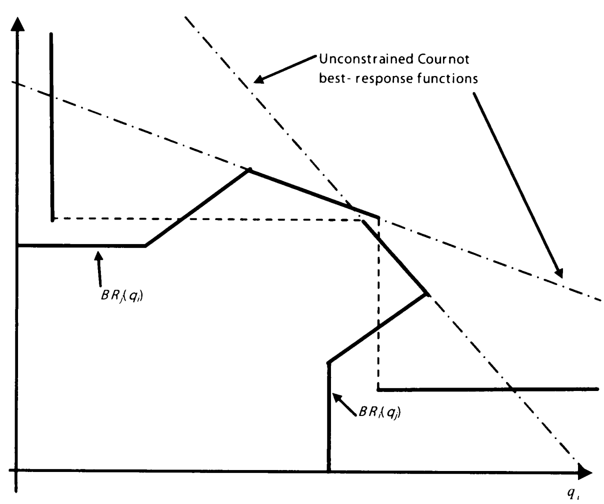


(a) Best Response Curves Without FTRs.

Figure 4. Illustration of the Effects of FTR Options on the Cournot Equilibrium (continued)



b) Best Response Curves With FTR option η_i^{ij} and η_j^{ji}.



(c) Best Response Curves With FTR option η_i^{ji}.

$$P_{ij}(q_i^{uoji-}, q_j^{r+}) = P(q_i^{uoji-} + K) - P(q_j^{r+} - K) = \left(\frac{(2 + \eta_i^{ji})\alpha}{2\alpha + a} - 2\right) \alpha K < 0 \quad (12)$$

This contradicts the assumption of achieving a passive/aggressive equilibrium since, with negative price difference, FTR options will not generate any additional payoffs and, therefore, firm *i*'s best response will not become the optimal passive output.

Q.E.D.

3.2.2 FTR Obligation Models

Similar analysis to that in section 3.2.1 shows that an FTR obligation in the sourcing direction will have a positive effect on achieving the unconstrained Cournot equilibrium by increasing the unconstrained Cournot best response region. On the other hand, an FTR obligation in the sinking direction will have a negative effect on achieving the unconstrained Cournot equilibrium.

3.3 Summary

We have analyzed the competitive effects of two forms of FTRs: FTR option, and FTR obligation. We considered how ownership of FTRs change the players' best responses and investigated the corresponding equilibrium by considering the intersection of both players' best responses.

First consider FTR options in the sourcing direction. Such FTR options do not change the range of conditions under which the Cournot response is the best response and so they do not have any effect on achieving the unconstrained Cournot equilibrium. Under the assumption that without FTRs the unconstrained Cournot equilibrium is achieved, such FTR options do not change the resulting equilibrium and so result in the same unconstrained Cournot equilibrium.

On the other hand, consider FTR options in the sinking direction. Such FTR options decrease the range of conditions under which the Cournot response is the best response and therefore make the unconstrained Cournot equilibrium less likely to be achieved. Such FTR options may result in a mixed strategy equilibrium instead of the unconstrained Cournot equilibrium. However, they cannot result in a passive/aggressive equilibrium.

Now consider FTR obligations in the sourcing direction. Such FTR obligations increase the range of conditions under which the Cournot response is the best response, making the unconstrained Cournot equilibrium more likely to be achieved. On the other hand, FTR obligations in the sinking direction decrease the range of conditions under which the Cournot response is the best response.

The results for FTR options and obligations are different to each other even in the cases where both types of FTR may yield the same payoffs to the right holder at equilibrium since we do not restrict the direction of flow when we analyze equilibrium. The following table summarizes the results. The effect of an FTR is deemed to be "good" if it increase the range of conditions under which the Cournot response is the best response, and, therefore, an FTR has positive effect on achieving the unconstrained Cournot equilibrium. On the other hand, it is deemed to be "bad" if it decreases the range of conditions under which the Cournot response is the best response.

Table 1. Competitive Effects for Each FTR Model

(B: bad effect, G: good effect, N: no effect)

	Sinking direction	Sourcing direction
FTR option	B	N
FTR obligation	B	G

Ownership of FTRs in the sinking direction owned by generating firms is uniformly bad. However, such FTRs have no role in hedging risk for the owner since they involve the increasing exposure of the firm to nodal prices at its location. From a policy perspective, such ownership of FTRs should be discouraged, as implied by the results of Gilbert et al. (2004).

On the other hand, ownership of FTRs in the sourcing direction by generating firms is uniformly good (FTR obligations) or has no effect (FTR options). Such FTRs hedge risk for the generating firm by reducing the exposure of the firm to nodal prices at its location. Such ownership of FTRs should be encouraged.

In several markets, such as ERCOT, there are limitations on the possession of FTRs that are aimed at mitigating market power. However, these limitations are typically independent of the location of the owner. The results in this section indicate that such a policy is inappropriate, both because it allows a generating firm to own FTRs in the sinking direction and also because it limits the ownership of sourcing FTRs by generating firms. To implement such a policy considering the location of the owner, there would need to be rules on acquiring FTRs both in an initial allocation auction and in any secondary market.

4. MODEL EXTENSION: ASYMMETRIC MARKETS

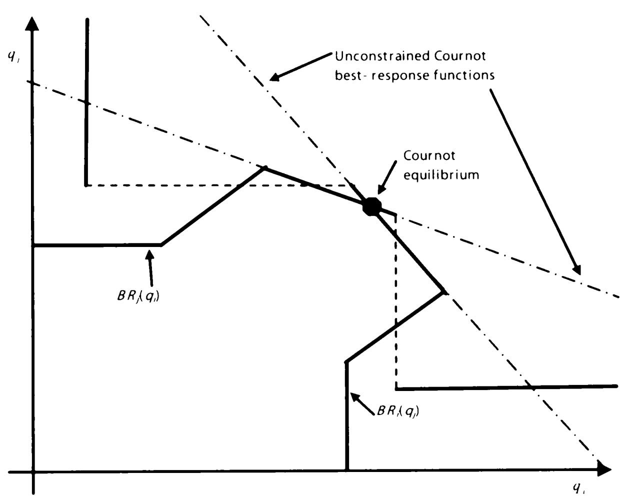
In the work of Borenstein et al. (2000), several extensions of the reference model were provided and analyzed. Most of them are also valid in other FTR models in a straightforward manner. In this paper, we comment on only the extension to asymmetric markets. However, Joung's dissertation (Joung, 2008) provides the extension to the case where one of the markets is competitive.

Borenstein et al. (2000) showed that for the reference model, if markets are asymmetric enough, then even a very thin transmission line can provide a pure strategy equilibrium: a passive/aggressive equilibrium. Moreover, they showed that, with a sufficiently large line, the unconstrained Cournot equilibrium is the unique pure-strategy equilibrium and that this is the same as the case of symmetric markets.

With our other FTR models, under certain conditions, a passive/aggressive equilibrium is possible even for the case where, without ownership of FTRs, the unconstrained Cournot equilibrium is the unique pure-strategy equilibrium. This shows that FTRs may effectively increase asymmetry of markets that, otherwise, is not enough to yield a passive/aggressive equilibrium. However, by the same reasoning as for the reference model, with a sufficiently large line capacity, the unconstrained Cournot equilibrium will be the unique pure-strategy equilibrium even with FTRs. Furthermore, results in Table 1 also hold for the asymmetric market case.

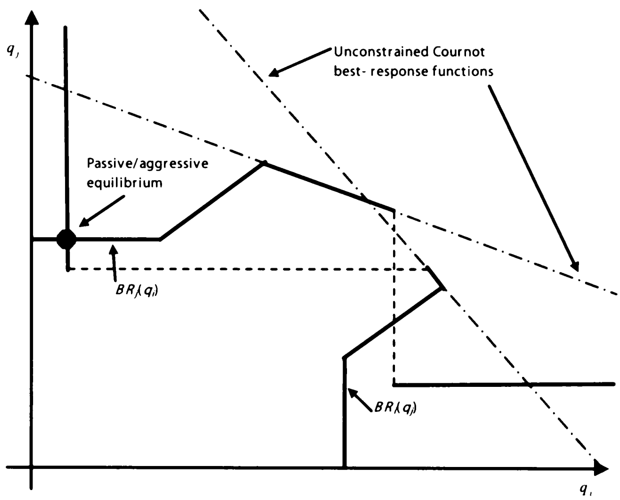
Consider a case where, without FTRs, asymmetry of markets is small enough to achieve the unconstrained Cournot equilibrium. Fig. 5(a) illustrates this case. Suppose that firm *i* possesses an η_i^{ji} FTR option. In this case, the resulting equilibrium may change from the unconstrained Cournot equilibrium to a passive/aggressive strategy equilibrium. This is illustrated in Fig. 5(b). Fig. 5(b) shows that by *i* possessing an η_i^{ji} FTR option, asymmetry of markets increases enough to result in a passive/aggressive equilibrium instead of the unconstrained Cournot equilibrium that is achieved without FTRs (Fig. 5(a)). Results in Table 1 also hold for this case.

Figure 5. Illustration of the Effects of FTR Options on the Cournot Equilibrium



(a) Best Response Curves Without FTRs.

Figure 5. Illustration of the Effects of FTR Options on the Cournot Equilibrium (continued)



(b) Best Response Curves With FTR Option η_i^{ji}.

5. NUMERICAL EXAMPLE

In this section, we present a numerical example for an asymmetric market that will help to make concrete the results from the previous sections. In this example, we consider varying demand in asymmetric markets and the inverse demand of each market is as follows:

$$P_i(q) = -5q + 5\beta,$$
$$P_j(q) = -0.5q + 0.5\beta, \tag{13}$$

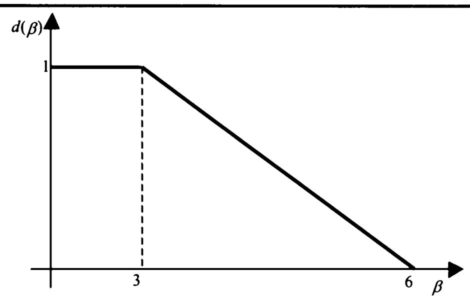
where the inverse-demand duration curve $d(\beta)$ for β is as shown in Fig. 6.

The cost function of each firm is as follows:

$$C_i(q_i) = \frac{q_i^2}{2} + \frac{q_i}{2} + 1,$$
$$C_j(q_j) = \frac{q_j^2}{4} + q_j + 1. \tag{14}$$

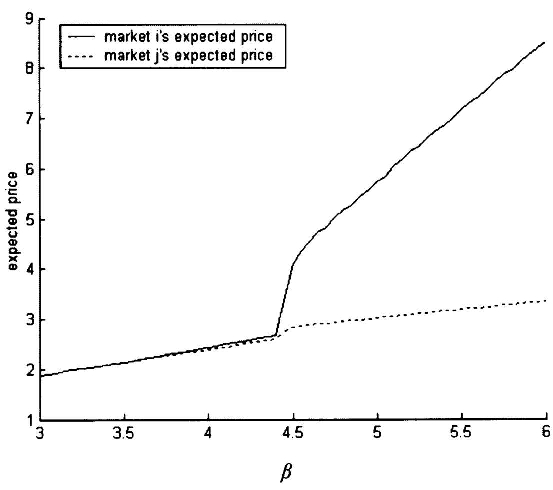
The capacity of the transmission line K is set to 3. With this setup, the market i is always an importing market at equilibrium whenever there is a flow on

Figure 6. Inverse-Demand Duration Curve



the transmission line. In this example, the mixed strategy equilibrium is computed using the fictitious play method described by Borenstein et al. (2000). Fig. 7 shows the expected price of each market as a function of the different values of β for the reference case; that is, without FTRs.

Figure 7. Expected Price Curves in the Reference Case



We consider FTR ownership of the generating firm in the importing market. We also consider 2 different cases according to the rights direction. For brevity of the paper, the detailed result is presented by expected price curve graphs only for the first case: FTR ownership of the generating firm in the importing market in the sinking direction.

5.1 Case 1: FTR Ownership of the Generating Firm in the Sinking Direction

In this case, firm i owns all the FTRs in the sinking direction. Both FTR models have the same results and Fig. 8 shows the results of the FTR option model compared with those of the reference case. Fig. 8(a) shows the expected price at market i and Fig. 8(b) shows the expected price at market j. In both markets, the expected price with FTRs is always higher than or equal to, and is never lower than that without FTRs for each possible value of β.

5.2 Case 2: FTR Ownership of the Generating Firm in the Sourcing Direction

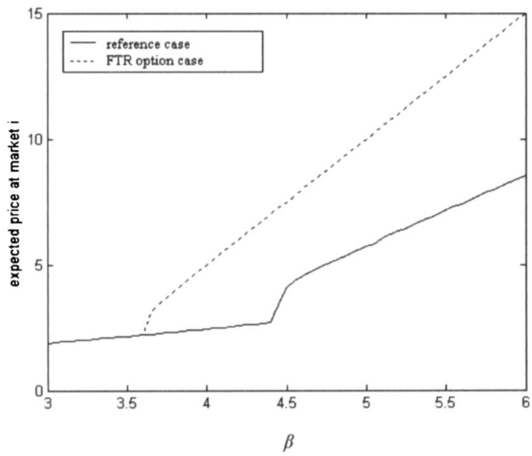
In this case, firm i owns all the amount of FTRs in the sourcing direction. The FTR option model does not have any effect on the expected price. For the FTR obligation model, the expected price at any market for FTR obligation case will not be higher than the expected price for reference case for each value of β.

6. CONCLUSIONS

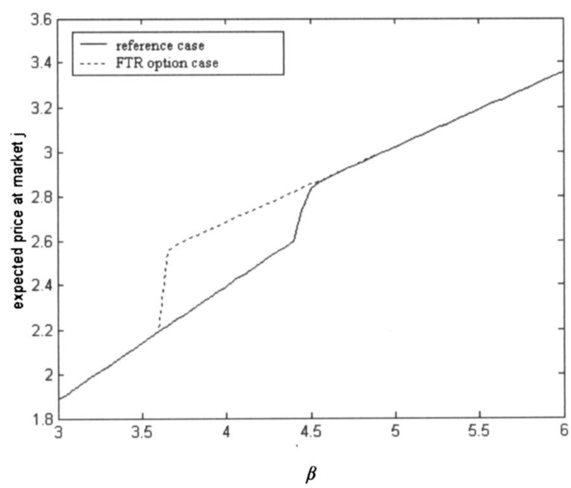
As stated in the work of Borenstein et al. (2000), the full benefits of competition can be achieved by connecting two markets with a sufficiently large capacity line so that each generator would compete over the merged market instead of over a residual market of its own. In this paper, we have demonstrated how to analyze the impact of ownership of FTRs on competition, and showed that, by introducing FTRs in an appropriate manner, the physical capacity needed for the full benefits of competition can be reduced. It has also shown that, by introducing FTRs, we may reduce the required physical capacity of the transmission line that is necessary to achieve a pure strategy equilibrium, particularly for achieving the unconstrained Cournot equilibrium that gives the full benefits of competition of a merged market. We have provided separate results for an FTR option model and for an FTR obligation model in this paper and the supplementary document.

We also extended the FTR models by considering asymmetric markets and by assuming that one of the markets is perfectly competitive. Asymmetry of markets makes it possible for the ownership of FTRs to change market equilibrium from the unconstrained Cournot equilibrium to a passive/aggressive equilibrium. By constraining one market to be competitive, we can show a similar result to that in the work of Joskow and Tirole (2000). Moreover, other results from the same model are also obtained and some of them show that FTRs may reduce the firm's market power while Joskow and Tirole showed only the result of enhancing the firm's market power. Based on the model, we also analyzed the competitive effects of ownership of FTRs in asymmetric markets in order for more practical applications of the theory. Competitive effects of each FTR model are evaluated and policy implications discussed. A numerical illustration of applying the

Figure 8. Expected Price Curves In Case 1



(a) Expected price curves at market *i*.



(b) Expected price curves at market *j*.

analysis is presented.

Finally, we observe that our model has assumed particular ownership of FTRs. In future work, we plan to analyze the incentives for acquiring FTRs and for entering into forward energy contracts. FTRs can be considered to be forward contracts for transmission service. We plan to investigate whether results analogous to Allaz and Vila (1993), where the joint equilibrium in the forward and spot market is more competitive than the spot market alone, also hold for FTRs.

ACKNOWLEDGEMENT

This research was supported, in part, by the National Science Foundation under Grant Number ECS-0422914. The authors would like to thank four anonymous reviewers for their comments.

REFERENCES

Allaz, B. and Vila, J.L. (1993). "Cournot Competition, Forward Markets, and Efficiency," *Journal of Economic Theory* 59: 1-17.

Borenstein, S., Bushnell, J., and Stoft, S. (2000). "The Competitive Effects of Transmission Capacity in a Deregulated Electricity Industry," *RAND Journal of Economics* 31: 294-325.

Cho, I.-K. (2003). "Competitive Equilibrium in a Radial Network," *RAND Journal of Economics* 34: 438-460.

ERCOT (2005). "The Market Guide," www.ercot.com.

ERCOT (2006). "ERCOT Nodal Protocols," www.ercot.com

Gilbert, R., Neuhoff, K. and Newbery, D. (2004), "Allocating Transmission to Mitigate Market Power in Electricity Networks," *RAND Journal of Economics* 35: 691-709.

Hogan, W.W. (2002). "Financial Transmission Right Formulations," Center for Business and Government, Harvard University.

Joung, M. (upcoming in 2008). Ph. D. dissertation, Electrical and Computer Engineering Department, University of Texas at Austin

Joskow, P., and Tirole, J. (2000). "Transmission Rights and Market Power on Electric Power Networks," *RAND Journal of Economics* 31: 450-487.

Leautier, T.O. (2000). "Regulation of an Electric Power Transmission Company," *The Energy Journal* 21: 61-92.

PJM (2005). "FTR Market Frequently Asked Questions", www.pjm.com.

Pritchard, G. and Philpott, A. (2005). "On Financial Transmission Rights and Market Power," *Decision Support Systems* 40: 507-515.

Schweppe, F., Caramanis, M., Tabors, R., and Bohn, R. (1988). Spot Pricing of Electricity. Boston: Kluwer Academics.

Stoft, S.E. (1999). "Financial Transmission Rights Meet Cournot: How TCC's Curb Market Power," *The Energy Journal* 20: 1-23.

Quick, D.M. and Carey, J.M. (2001). "An Analysis of Market Power Mitigation Strategies in Colorado's Electricity Industry," *The Energy Journal* 22: 55-77.

Willems, B. (2002). "Modeling Cournot Competition in an Electricity Market with Transmission Constraints," *The Energy Journal* 23: 95-125.